From Mendel to Me

Constructing Genetics Knowledge Through Historical Problem-Based Learning

by John Pecore and Corey Nagle

What do peas and a guy from the 1800s have to do with my life?” This or similar questions are sure to cross the minds of many middle school students as they begin their study of genetics. Mendelian inheritance and Punnett squares are often taught to seventh graders through a lecture-and-copy approach. As the opening question demonstrates, there is room to improve science education through alignment with the *Next Generation Science Standards* (NGSS Lead States 2013). How can teachers engage students in constructing knowledge and deepening understanding about a topic such as Punnett squares? One answer is to use historical problem-based learning (Pecore 2009).

What is historical problem-based learning?

Similar to problem-based learning, *historical problem-based learning* (historical PBL) uses an ill-structured problem or event to engage students and drive construction of knowledge. Ill-structured problems may be based on political, social, economic, or scientific questions that have neither clear goals nor complete information (Simon 1973; Voss 1988). In the case of historical PBL, the problem is centered on a historical event, Mendel’s life and work. In historical PBL, learning occurs through gathering facts and generating hypotheses, determining what is needed to solve the problem, researching and experimenting to acquire new information, applying new information to model construction, sharing new learning with peers, and completing supplemental activities to address the historical event (Pecore 2009).

Teaching Punnett squares using history

To teach Punnett squares, consider using the history of Gregor Mendel's life and the results of his investigations of traits and heredity. Mendel's life is presented in the following lesson through several informational text vignettes.

Exploring Mendel's life and investigations

Students participating in this lesson had prior knowledge of cell structure and division, but were not familiar with genetics and Punnett squares. This lesson is an opportunity for students to experience genetics from Mendel's perspective and construct an understanding of traits. Students were given a pretest prior to beginning the unit to allow the teacher to formatively assess their current understanding of basic genetics. A sample pretest is included in the online supplements at *www.nsta.org/middleschool/connections.aspx*.

To introduce the lesson, students are reminded that science is a process of gathering information and learning and that scientists can learn from their failures. Students are asked to consider how failure and struggle were part of the life of Gregor Mendel in his early years as a student via a short article written by the authors (see Vignette 1 in the online supplements). After students independently read the article about Mendel's struggles and failures, the teacher facilitates a discussion in which students relate personal struggles or failures to Mendel's early years. The class discussion is initiated using the following questions:

- What do you have in common with Gregor Mendel?
- Does anyone speak a different language at home?
- Think about a time when you have not done your best on an exam. How did you feel? How did you react?

The reading and discussion will take approximately 15–20 minutes. The teacher may modify the lesson by assigning the reading for homework prior to the discussion in class. Additionally, the teacher may consult with other teachers to create versions of the article in different languages or at different levels to meet the needs of individual students.

After the initial discussion, which may require sensitivity as students reveal their thoughts and feelings, formatively assess students' background knowledge as it specifically applies to the terms *characteristics* and *heredity* through class discussion and by asking questions such as, "Gregor Mendel wondered why there were differences between peas. Let's think about a fruit that we are more familiar with in our cafeteria. Have you ever noticed that some apples taste sweeter than others?" This discussion begins to move student thinking from Mendel's early life to his research interests and allows the teacher to gauge student understanding of characteristics and heredity. Students are then asked to describe an apple. They usually mention characteristics such as the peel, color, taste, and shape. The teacher presents students with a Red Delicious apple and a green Granny Smith apple and asks them to discuss the similarities and differences in the apples' characteristics based on their observations. Students should be reminded not to consume food in the science classroom. The comparison can be facilitated by asking students the following questions:

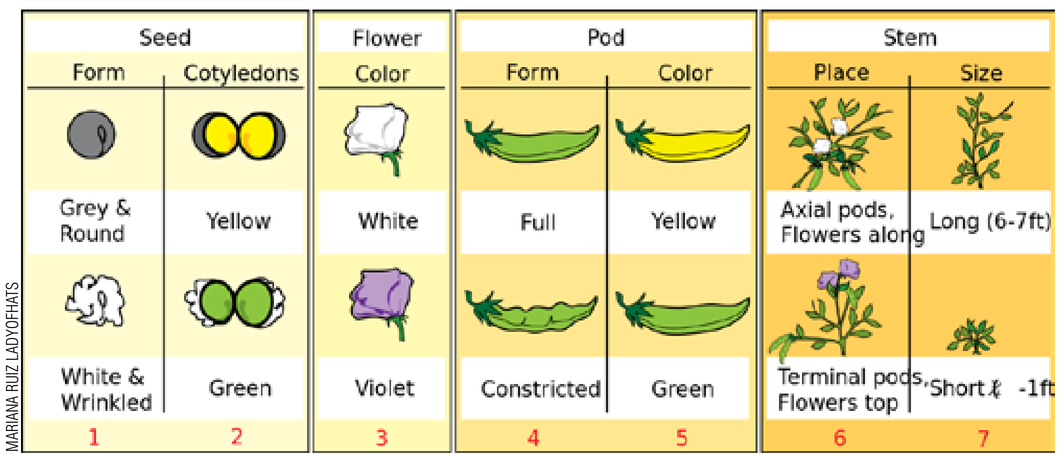


Diagram showing the seven "characters" observed by Mendel.

- What characteristics make these apples similar or different? Students can consider physical appearance, taste, and other features.
- Students can hypothesize: Why do you think the Red Delicious apples taste sweeter than Granny Smith apples?
- Students can hypothesize: Why do you think some apples are red and others green?
- Students can hypothesize: Where do apples get the characteristics, or traits, they exhibit?

Explain to students that just as we observe differences in apples, Gregor Mendel observed differences in the plants and animals on his parents' farm. Tell students that they are going to learn about Gregor Mendel's investigations into these differences that resulted in him being known as the "father of modern genetics." Continue the historical storyline by reading a brief selection about Mendel's investigations in heredity through a short article composed by the authors (see Vignette 2 in the online supplements). Teachers may also choose to locate or compose their own articles to meet different content standards or to match the reading levels or needs of their individual students. This allows students to gain perspective about what was known about genetics during Mendel's time and what Mendel was investigating and hoping to learn. Students can then be asked to reference the text and generate research questions that Mendel could have been addressing throughout his work. For example, "What do you think Mendel wanted to learn more about? Create possible research questions that reflect what Mendel was hoping to address in his work." As students build background knowledge and engage in discussion on the historical storyline, they become intrigued and motivated to learn about Mendel's research and discoveries. Students may generate questions such as, "Why do children from the same parents look different?" or "How do we get different shapes and colors of fruits and vegetables?" If students are struggling to generate research questions, the teacher may facilitate a discussion to draw out ideas or teach a mini-lesson about how to generate research questions.

These first two reading selections, aligned with the historical PBL model described by Pecore (2009), engage students and initiate the process of gathering facts. The third reading selection (Figure 1), written by the authors of this article, presents to students an overview of Mendel's pea plant investigations. As part of this third text selection and prior to introducing students to Punnett squares, students are given data from Mendel's investigation and analyze and interpret the data. Students begin analyzing the data individually, then in small groups. Students are asked to look for trends, patterns, or other evidence to support potential conclusions from the data. Students can be asked questions such as: Are there patterns in Mendel's data? How can you tell? How would you explain them? The teacher may offer individual or small group assistance as needed, but the emphasis is on students constructing possible explanations of the trends or patterns ob-

FIGURE 1 **Mendel's data**

From the summer of 1856 through 1863, Mendel conducted research on pea plants because of their purity and more easily observable characteristics. His research question was similar to "How many different forms would result from the random fertilization of two kinds of pea plants?" He hypothesized that the existence of factors for each characteristic responsible for different variations of a trait don't occur together (see Resources).

In other words, Mendel explored the question "If you crossed a long-stem pea plant with a short-stem pea plant, could you predict the result of creating a long-stem or short-stem pea plant?" Mendel carried out his experiment and collected the following data.

Characteristic category	Type of characteristic	Number of plants showing trait	Type of characteristic	Number of plants showing trait	Ratio
Seed shape	Round	5,474	Angular	1,850	2.959:1
Pod color	Green	428	Yellow	152	2.816:1
Stem length	Long	787	Short	277	2.841:1
Total number of plants	Dominant	6,689	Recessive	2,279	2.935:1

Data are used to inform conclusions and help scientists learn new things. Take a close look at Mendel's data. What patterns do you see in the data? How can the data help explain the traits and how they are inherited?

served in the summary of Mendel's data presented in the first part of Figure 1. Time allotted for this analysis will vary depending on the ability and background of students, but will likely range from 10–15 minutes. Following the time for analysis, students can be given time (5–10 minutes) to discuss their interpretations of Mendel's data in small groups; the whole class discusses Mendel's accomplishments and data. The teacher may direct students to summarize or record the main points discussed in the small-group and whole-group discussions. The focus should be on student questions, interpretations, and ideas; if necessary, the teacher may guide students by asking them to go back to the data, to look for patterns, or build on previous responses to go deeper. Questions can include:

- Why don't you go back to the data?
- What do the data tell you?
- Can you figure that out using the data?
- Are there any patterns in the data?
- What do you think the patterns tell you?
- How do you know that from the data?
- What evidence supports your answer?
- Based on what have said, can you get more information about that?

The individual, small-group, and whole-group interaction with Mendel's data serves several purposes. The teacher's initial directions ask students to search for patterns in the data. Patterns is identified as one of the crosscutting concepts in the *NGSS*. As the teacher visits individuals and small groups, students are asked to point out what they thought were patterns in the data, using evidence from the text or the data set to support their explanations (see Figure 1). This requires students to use the data as evidence to support their thinking, which links to both the *NGSS* (NGSS Lead States 2013) and the *Common Core State Standards* (*CCSS*) (NGAC and CCSSO 2010) (see the sidebar on p. 34 for the lesson alignment to the *NGSS*).

Cause and Effect is also identified as a crosscutting concept in the *NGSS* and fits the logical progression of this lesson and of the historical storyline. After students begin identifying patterns, they are asked to consider what they think caused those patterns. The scientific process allows students to keep the pattern in mind as teacher questions push students to conjecture about cause and effect in traits and heredity.

Having the opportunity to mull over the data individually and in a small group, which could last 10 to 20 minutes, students are prepared to share as part of a whole-class discussion on the data. As facilitators of the discussion, teachers have four goals that are consistent with the Technical Education Research Centers Inquiry Project as outlined by Doubler and McWilliams (2011) and aligned with speaking and listening skills specified in the *CCSS*. The goals, drawn from the work of Doubler and McWilliams (2011), are the following:

- to help students develop their own thinking with think time and clarifying thinking through guiding questions,
- to help students engage in communication that involves listening to ideas from peers,
- to help students develop reasoning through the use of supporting evidence and the ability to address counterclaims, and
- to help students explain their reasoning and the reasoning of peers engaged in discussion.

Speaking and listening goals fit with the need for scientific communication in *NGSS* and can both be addressed using "talk moves" to ask probing, open-ended questions that require student thought, evidence to support answers, and ongoing discussion of ideas (Doubler and McWilliams 2014). Question stems include:

Elaboration

- Can you say more about that?
- So are you saying ... (teacher repeats/rephrases and allows student to agree/disagree)?

Listening to others

- Can someone repeat what Student A just said?

Evidence

- Why do you think that?
- Can you give an example from the reading or the data?
- What is your evidence?
- Do you think it always happens the same way?

Thinking with others

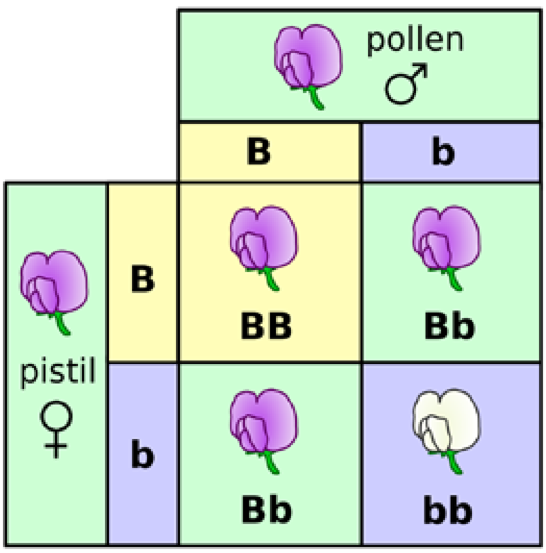
- Do you agree or disagree? Why?

Students need practice to build speaking and listening and scientific argumentation and communication skills (Berland and Reiser 2010). In the beginning, teachers might pose more questions and model appropriate behaviors, but students are able to direct the discussion with fewer prompts as time progresses, allowing more opportunities for engaging in discussion to practice communication skills.

Activity to further understanding

Students are able to make observations using the data as evidence in supporting relationships between traits (see Vignette 3 online and illustration below). To advance student understanding, introduce them to the Punnett squares as a format for organizing Mendel's explanation of traits. The teacher may ask students to consider ways to organize the data or predict data based on two possible parents. Students are able to begin seeing the connection between the data and the Punnett squares as a means for predicting the data. To deepen student knowledge, consider implementing a version of a common activity in basic genetics instruction: predicting traits through flipping a coin (see Mendelian Genetics Pea Activity online). Students are organized into pairs and the activity, which will likely take about 30 minutes, is guided to facilitate investigation of the content of the DCI and centered on peas in order to maintain consistency with the historical narrative being used in the unit.

The traditional activity focuses on characteristics of pea plants, which include tall or short plants, round or angular seeds, and green or yellow peas. Each pair of students is split in half when creating the original pea plants, so two different peas are created for crossing later in the activity. Students create the peas by flipping a coin, beginning with the trait of tall or short plants and progressing through the three traits. The coin-flipping exercise serves as an extension of learning in the historical PBL model, giving the common activity new meaning as students construct knowledge. Students flip the coin twice for each trait. If the coin lands on heads, then it indicates a dominant allele and a capital letter is recorded. If the coin lands on tails, then it indicates a recessive allele and the corresponding lowercase letter is recorded. As students complete the activity, they learn about the concepts of phenotype, genotype, allele, homozygous, heterozygous, dominant, and recessive. This activity can allow students to consider the follow questions: How do traits vary between generations? What evidence supports your conclusions? Where do the variations in traits come from? What evidence do you have? Once students understand the ideas of each, attach the vocabulary to the idea. For example, once students understand the idea that each pea has a pair of genes that determines the trait, the teacher can attach the vocabulary word *genotype* to the idea.



MADELEINE PRICE BALL

Punnett square Mendel flowers.

Once students determine the genotypes of their plants through the coin flip, they sketch pictures of the peas and summarize the traits in writing, including an identification of the traits as dominant or recessive. The two different peas in the group are then crossed. Students are asked to determine how they would organize the information about the cross of the peas. Recalling the use of matrices in mathematics class and the earlier introduction of the Punnett square, students are guided to the idea of a square to show the two parents and their contributions to the offspring. Throughout the activity, teachers should check with each pair of students to both answer and pose questions to guide the use and interpretation of Punnett squares (see Vignette 3 online). Students may be guided with questions that could include: Do you think changes in parents could affect offspring? Why do you think this?

Elaboration of Mendel's achievements

Student learning from the Punnett square activity is then used as they continued to learn through the historical storyline. The teacher can provide an opportunity for students to reflect on what they have learned in the lesson up to this point. For a reflection like this, the teacher may simply ask students to summarize what they know or have figured out so far. Depending on the group of students, the teacher may facilitate an oral review or ask them to write a summary. After reflection and review, students are once again given a brief reading selection that addresses Mendel's achievements and contributions to science (see the online supplements). The article also presents evidence from other sources that corroborate Mendel's findings. Students are asked to summarize their learning about Mendel, genetics, heredity, and Punnett squares from the lesson through brief written summaries and sharing orally. The teacher may provide questions to guide student reflection, such as: What have I learned about Gregor Mendel? What have I learned about "doing science"? What did Mendel teach us? What else do you want to know?

FIGURE 2 Mendel's legacy

In 1865, Mendel presented his findings in two lectures to the Natural Science Society in Brno. After his presentations, Mendel's work was published as *Experiments on Plant Hybrids* in the Natural Science Society's journal. Although Mendel presented and published his work, it was not fully understood during his lifetime and did not attract much attention. Many thought Mendel demonstrated what was already known about hybrid offspring reverting to their previous traits. Scientists, including Mendel, also did not understand how the experiments with pea plants could be applied to other organisms.

Mendel died in 1884 at the age of 61 without seeing his work gain recognition. In fact, Mendel's ideas remained mostly unread for nearly 35 years after their publication. In the early 1900s, three independent scientists each rediscovered Mendel's published article and work. The work of these geneticists, botanists, and biologists built on Mendel's work; some even replicated Mendel's experiments and gathered data consistent with Mendel's. Eventually, Mendel's conclusions were referred to as Mendel's laws. Scientists have identified a number of traits that follow the pattern of Mendelian inheritance, but not all genetics are as simple as the traits described by Mendel. Even so, Mendel's work is the foundation of understanding genetics and the reason Mendel is viewed as the father of modern genetics (see Resources).

Resources used to create the vignettes:

Biography.com. Gregor Mendel. *www.biography.com/people/gregor-mendel-39282.*

Dao, C. 2008. Man of science, man of God: Gregor Johann Mendel. *Acts and Facts* 37 (10): 8.

Franklin, A., A.W.F. Edwards, D.J. Fairbanks, D. L. Hartl, and T. Seidenfeld. 2008. *Ending the Mendel-Fisher controversy.* University of Pittsburgh Press: Pittsburgh, PA.

Magner, L.N. 2002. *A history of the life sciences.* 3rd ed. New York: M. Dekker.

Olby, R. 2014. Gregor Mendel: Austrian botanist. *www.britannica.com/biography/Gregor-Mendel.*

The Saylor Foundation. 2012. *Punnett square. www.saylor.org/site/wp-content/uploads/2012/09/1.5-Punnett-Square.pdf.*

Wellnitz, W.R. 2015. Mendel, Gregor, Czech geneticist 1822–1884. *www.biologyreference.com/Ma-Mo/Mendel-Gregor-Czech-geneticist-1822-1884.html.*

To reinforce the learning from the readings and activity in this lesson, students need to elaborate on the evidence and experiences from the historical storyline created by the vignettes (Pecore 2009). Learning in this lesson is reinforced through a final activity that applies Mendelian genetics to an example other than pea plants. A genetics activity that applies to the farm life that inspired Mendel helps maintain consistency with the historical storyline. One possibility is the Goat Mendelian Genetics Activity that expands student understanding from plants to animals by focusing on certain characteristics of goats (Kohn 2013; see References). While the activity focuses on goats, other examples related to specific student interests could be used to engage various student populations as long as the focus is on Mendelian genetics and consistent with the standards being addressed. As an alternative, teachers with the technology and a school subscription to Gizmos (see Resources) could consider using the Chicken Genetics simulation. Technology can also assist with extending the lesson through virtual lab investigations available online at sites such as Mendel's Peas or New Path Learning (see Resources).

For the Goat Mendelian Genetics Activity, students work with a partner to complete the activity and to record information on the lab handout (Kohn 2013). Each partner creates one parent goat by determining six characteristics of each parent goat using a coin flip. Students are then responsible for identifying and justifying what they consider to be the three most important traits out of the six presented in the investigation. Students share their created goats with the class and are given the task of choosing a goat from those presented that would give the best chance of achieving the desired traits when crossed with their own goats. Students create Punnett squares to show the cross of two parent goats created in class for the three chosen traits. Group progress is monitored through the teacher circulating the room and engaging each pair of students in discussion about the parent goats and student choices of important traits. Students have to interpret and use the information from their goat Punnett squares to determine the most likely outcome for each of the three traits. Students present the resulting goat through a drawing, discussion, and written explanation. To close the lesson, students discuss the fourth reading (Figure 2), which explains Mendel's scientific legacy in the field of genetics.

Assessing student learning

Student learning is assessed in various ways before, during, and at the conclusion of the lesson. Prior to the lesson, students complete a pretest, allowing for determination of students' prior knowledge of genetics content. Class discussions and interactions with students provide opportunities for giving students feedback as part of a formative assessment. Finally, a posttest administered at the end of the lesson assists with measuring student growth in content knowledge. The lessons' pre- and posttests are available in the online supplemental materials.

Classroom instruction suggestions

Teachers should anticipate reading and discussion of each vignette to take 15 to 20 minutes. Depending on the students present in the class, teachers can choose to differentiate instruction in the historical PBL model by creating vignettes at various reading levels, recording readings of the vignettes, or modeling strategies for reading nonfiction texts. This lesson enables teachers to use flexible grouping, which provides an opportunity for regrouping students in a variety of ways throughout the lesson. Random grouping strategy can be used for the first reading to allow students to get to know each other. Homogeneous or similar-ability grouping based on reading level is a good option for the second reading, where teachers can provide additional scaffolding and assistance to students. Heterogeneous or mixed-ability grouping is a viable option for the third and fourth readings, where students are expected to perform the higher-order thinking task of analyzing and synthesizing data. For the last reading, student-choice grouping can be used to enable students to comfortably share their thoughts about Mendel's legacy. The coin-flip pea activity typically takes approximately 25 to 30 minutes, while the final goat activity can last an entire 50-minute class period.

When creating a historical storyline to promote student construction of knowledge, the teacher may want to consider an anchoring event in the life of the scientist that will catch students' attention. The storyline may then progress through the significant accomplishments and contributions to the field of science being studied. The process should provide students with bits of information and allow for students to analyze information and data in order to construct and refine their understanding of the science content. There are many resources online and in school libraries that could provide background information for the creation of text selections in such a lesson.

Conclusion

Finding ways to engage students in constructing knowledge about concepts such as Punnett squares can be difficult. Using historical PBL to teach Punnett squares addresses challenges in instruction while aligning with new standards found in both the *NGSS* and the *CCSS*. First, the historical PBL lesson can overcome the time constraints faced by science teachers. Due to pacing of instruction, having students recreate Mendel's experiments to trace traits and determine heredity is likely impractical. However, by following the historical storyline and reviewing primary-source data, students can engage in minds-on science.

The second challenge addressed through the use of historical PBL is assisting students with uncovering examples of scientific reasoning and investigation. Uncovering scientific reasoning and investigation within the historical context allows students to see how scientists have helped build our current understanding of the world around us. Historical PBL can bring both the historical and current processes of scientific reasoning, investigation, and communication to life in the classroom and can simultaneously teach content and skills. ■

References

Berland, L.K., and B.J. Reiser. 2010. Classroom communities' adaptations of the practice of scientific argumentation. *Science Education* 95 (2): 191–216.

Doubler, S., and H. McWilliams. 2011. Checklist: Goals for productive discussions and nine talk moves. *http://inquiryproject.terc.edu/shared/pd/Goals_and_Moves.pdf.*

Doubler, S., and H. McWilliams. 2014. The inquiry project: Seeing the world through a scientist's eyes. *http://inquiryproject.terc.edu.*

Kohn, C. 2013. Goat Mendelian genetics activity. *Agricultural sciences. http://communities.naae.org/servlet/JiveServlet/download/4743-2-7309/Goat Mendelian Genetics (Coin flip).docx.*

National Governors Association Center for Best Practices and Council of Chief State School Officers (NGAC and CCSSO). 2010. *Common core state standards.* Washington, DC: NGAC and CCSSO.

NGSS Lead States. 2013. *Next Generation Science Standards: For states, by states*. Washington, DC: National Academies Press. *www.nextgenscience.org/next-generation-science-standards.*

Pecore, J.L. 2009. A study of secondary teachers facilitating a historical problem-based learning instructional unit. PhD diss., Georgia State University. *http://digitalarchive.gsu.edu/msit_diss?52.*

Simon, H.A. 1973. The structure of ill structured problems. *Artificial Intelligence* 4 (3–4): 181–201.

Voss, J.F. 1988. Problem solving and reasoning in ill-structured domains. In *Analyizing everyday explanation: A casebook of methods,* ed. C. Antaki, 74–93. London: SAGE Publications.

Resources for expanding the lesson

Gizmo—*www.explorelearning.com*
Mendel's Peas—*www2.edc.org/weblabs/Mendel/MendelMenu.html*
New Path Learning—*www.newpathlearning.com/MML/HEREDITY/files/PeaLab.swf*

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Connecting to the *Next Generation Science Standards* (NGSS Lead States 2013)

Standard MS-LS3: Structure, Function, and Information Processing *http://nextgenscience.org/msls3-heredity-inheritance-variation-traits*		
Performance Expectation The materials, lessons, and activities outlined in this article are just one step toward reaching the performance expectation listed below. MS-LS3-2. Heredity: Inheritance and Variation of Traits: Develop and use a model to describe why asexual reproduction results in offspring with identical genetic information and sexual reproduction results in offspring with genetic variation.		
Dimension	**Name or *NGSS* code/citation**	**Matching student task or question taken directly from the activity**
Science and Engineering Practice	Obtaining, Evaluating, and Communicating Information	Students will develop an explanation for the data from Mendel's trials. Students read and evaluate the information presented in different sources. Students must communicate the explanation to their peers for feedback and critique.
Disciplinary Core Ideas	MS-LS3.A: Inheritance of Traits • Genes are located in the chromosomes of cells, with each chromosome pair containing two variants of each of many distinct genes. Each distinct gene chiefly controls the production of specific proteins, which in turn affects the traits of the individual. Changes (mutations) to genes can result in changes to proteins, which can affect the structures and functions of the organism and thereby change traits.	How do traits vary between generations? What evidence supports your conclusions? Where do the variations in traits come from? What evidence do you have?
Crosscutting Concepts	Patterns Cause and Effect	Are there patterns in Mendel's data? How can you tell? How would you explain them? Do you think changes in parents could affect offspring? Why do you think this?

Connections to the *Common Core State Standards*

CCSS.ELA-Literacy.RST.6-8.1
CCSS.ELA-Literacy.RST.6-8.4
CCSS.ELA-Literacy.RST.6-8.7
CCSS.ELA-Literacy.SL.8.1
CCSS.ELA-Literacy.SL.8.5
CCSS.Math.Content.7.SP.C.7